CHARACTERIZATION AND ANALYSIS OF BACK-TO-BACK BARRIER-N-N+ (bbBNN) VARACTOR DEVICES FOR MM- AND SUB MM WAVE FREQUENCY MULTIPLIERS

Debabanl Choudhury, R. Peter Smith, Anttl Ralsanen, Margaret A. Frerklng and Suzanne Martin

Jet **Propulsion** Laboratory
California Institute fo 1 ethnology, Pasadena, CA 91109

ABSTRACT

This paper addresses characterization and analysis of planar back-to-back Barrier-N-N^+ (bbBNN) devices for mm- and sub mm- wave frequency multiplier applications. A technique has been developed for measuring planar bbBNN devices with an HP 851OB network analyzer, which gives both series resistance and voltage dependent capacitance of the device. Results show that bbBNN devices do not have high series resistance like Barrier-Intrinsic-N^+ (BIN) devices. Efficiency of bbBNN devices has been calculated using large signal analysis. The embedding impedance requirement has also been analyzed. Theoretical and experimental analysis shows that planar bbBNN devices are very promising for terahertz and space applications.

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SUMMARY

MOTIVATION

Planar varactor devices are being developed to replace whisker contacted devices in order to improve the performance and ruggedness of spaceborne submillimeter wave heterodyne receivers [1]. It is expected that the back-to-back Barrier-N-N+ (bbBNN) devices can be made to operate efficiently at frequencies over one terahertz [2-5]. Lower leakage current in these bbBNN devices provides an advantage over the conventional Schottky devices.

DEVICE DESCRIPTION

Details regarding appropriate BNN layer structures have been addressed before [5]. The structure of a GaAs based BNN diode, from the top surface down, is (1) a thin GaAs cap layer (optional), (2) an AlGaAs layer that is sufficiently thick to preclude tunneling but sufficiently thin to allow a large capacitance per unit area (15 to 20 nm of $Al_{0.45}Ga_{0.55}As$ is typical), (3) a highly doped (delta doped) region in order to ensure that the high capacitance mentioned above is achieved at zero voltage, (4) a moderately doped GaAs drift/varactor region in which ail of the doping can be depleted with little parasitic conduction to the metal contact pads, and (5) a highly doped region that provides a low resistance path between the two metal contact pads. The layer structure is shown schematically in Fig, 1. The fabrication process is described in details in [4] and a back-to-back BNN varactor is illustrated in Fig.2. A photograph of the device is shown in Fig.3.

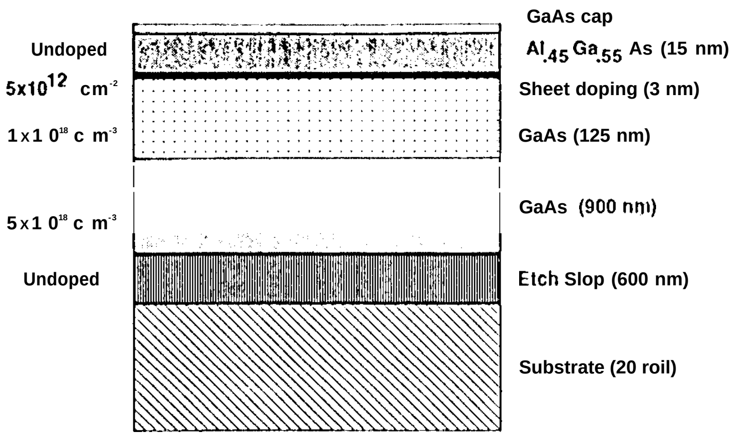


Fig.1 A typical MBE grown GaAs/AIGaAs layer structure for BNN diodes used in this study.

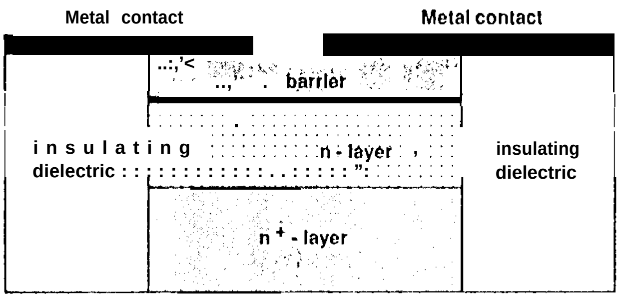


Fig.2 Back-to-back BNN Varactor

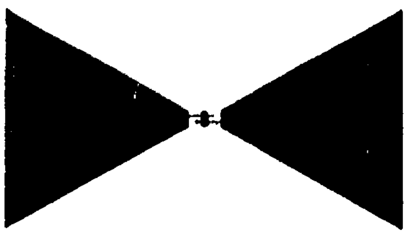
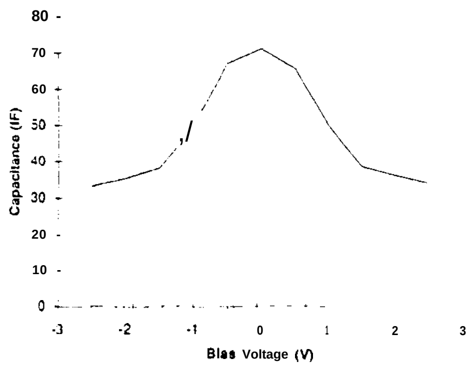
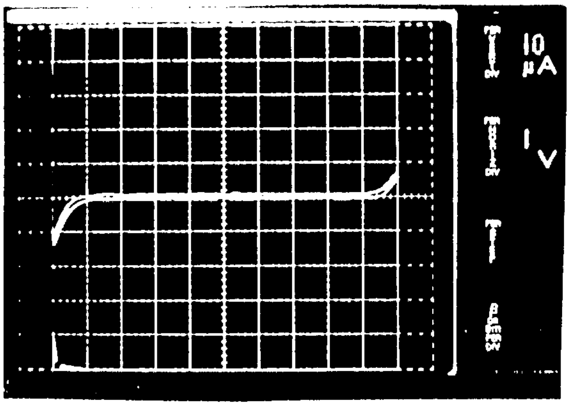


Fig.3 Backlit photograph of central portion of the device. The small dark rectangle in the centre is the approximately 4X16 micron^2 mesa. The larger dark portions with the thinner protrusions (2 micron fingers) are the Ti/Pt/Au pads. The remaining area is quartz.

bbBNN VARACTOR CHARACTERIZATION

Devices were first characterized by measuring the DC current/voltage (I-V) and capacitance/voltage (C-V) curves. Fig.4(a) shows the 1 MHz capacitance of a 4X8 micron device. Fig. 4(b) shows the DC leakage current, which is many order of magnitude lower than would be observed with conventional Schottky diodes. The series resistance of the device cannot be determined in the conventional way from the DC I-V curve.





(a) (b)

Fig.4 Measured (a) C-V and (b) I-V characteristics of a 4x8 micron^2 bbBNN varactor diode.

A special mount was designed for mounting the planar bbBNN devices to carry out measurements with a HP 851 OB vector network analyzer. Measurements were done at 1-20 GHz with 10 dB source level and 20 dB port attenuation. The results were fitted with a linear equivalent circuit model using HP's Microwave Design System (MDS). This technique gives both the series resistance and the voltage dependent capacitance of the device. Fig. 5 shows a schematic diagram of the device mounted in a test mount (see also ref. 6). Fig.6 shows measured S1 l-response at zero bias voltage. Fig.7 illustrates the equivalent network of the test mount and the varactor device. Fig.8 gives the C-V curve of a bbBNN device derived from this new technique. Series resistance values below 10 Ohm were measured.

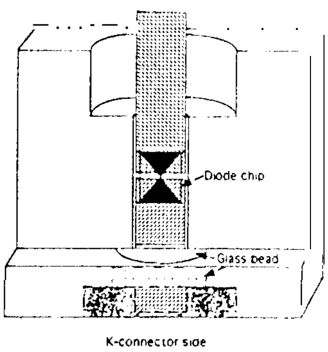


Fig.5 Schematic diagram of the planar bbBNN device in a test mount without the cover..

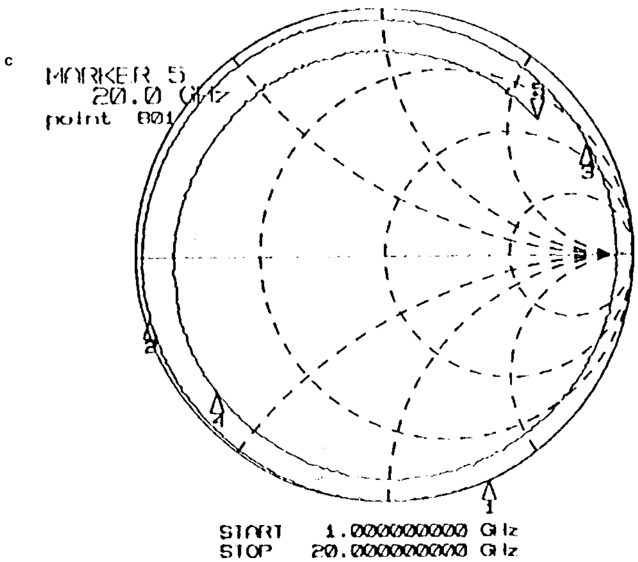


Fig.6 Measured S11 - response a 1-20 GHz of the bbBNN device at zero bias voltage.

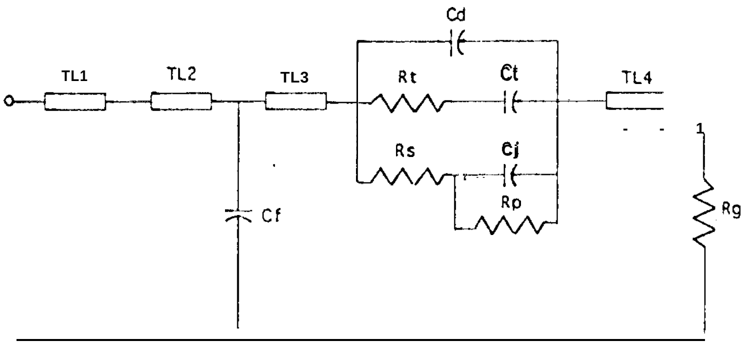


Fig.7 Equivalent circuit of the device in the test mount.

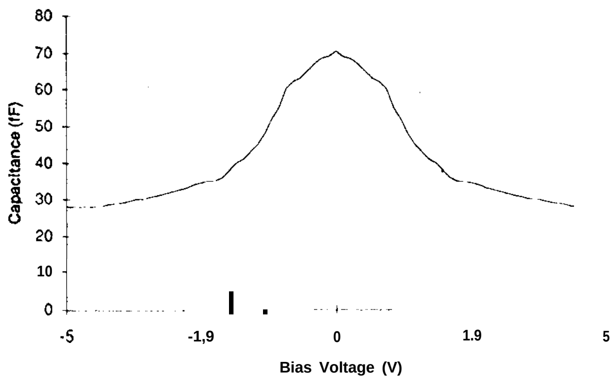


Fig.8 C-V characteristic of the bbBNN device derived from the 1-20 GHz measurement.

LARGE SIGNAL ANALYSIS

Measured C-V and I-V characteristics of Fig.4 have been used to carry out large signal analysis of bbBNN devices. A modified version of nonlinear program based on Siegel et. al [7], has been **used** in order ot calculate the tripling efficiency of bbBNN devices. Since series resistance is important in evaluating the device performance, calculations were carried out for a range of resistances. Fig.9 presents efficiency versus input power for a bbBNN tripler to 200 GHz with series resistance of the device as a parameter. Superimposed are the peak voltages and currents generated by the tripler. Theoretical efficiency is found to be high at lower input power levels. Due to very low leakage current, efficiency of the device does not degrade when the measured I-V characteristic is included.

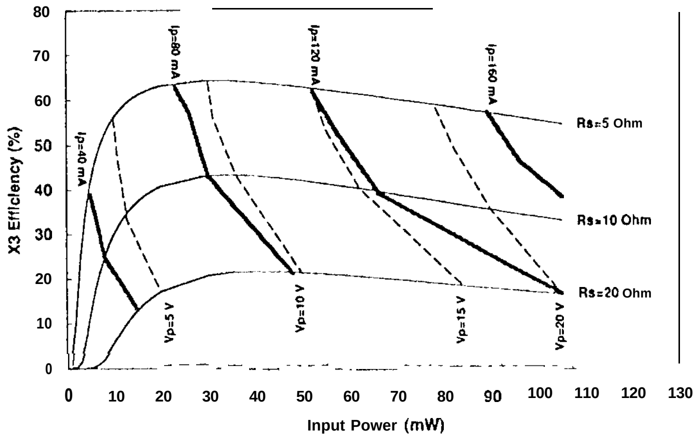


Fig.9 Calculated tripling efficiency to 200 GHz for bbBNN varactor with series resistance of the device as a-parameter.

The large signal analysis also provides the optimum embedding impedances required to maximize the multiplier performance. In Fig.1 O, the real and imaginary part of the optimum impedances are plotted for different series resistance of the device. At low input power real part is same as the device series resistance, while the input imaginary impedance is the impedance corresponding to the maximum capacitance at the input frequency.

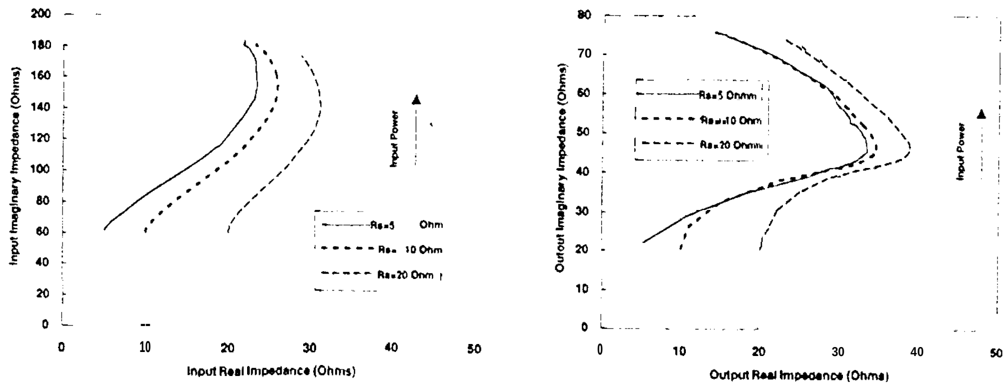


Fig.1 O Input and output circuit optimum embedding impedances calculated by the large signal analysis, parameterized by series resistance over a range of input powers.

CONCLUSIONS

A new technique has been developed to characterize planar bbBNN devices using automatic network analyzers. Measured device characteristics compare very well with those using other techniques. Lower leakage current of these devices help to improve the multiplier performance. bbBNN varactor devices are found to have very low series resistance compare to BIN devices [8]. Moreover, high efficiency at lower input power levels makes these devices very attractive for submillimeter wave frequency multiplier applications.
Experimental work with a tripler to 200 GHz is under way and will be reported in the Conference.

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